RECOMMENDATION ITU-R SA.1259

FEASIBILITY OF SHARING BETWEEN SPACEBORNE PASSIVE SENSORS[*] AND THE FIXED SERVICE FROM 50 TO 60 GHz

(Question ITU-R 216/7)

(1997)

The ITU Radiocommunication Assembly,

considering

a) that unique atmospheric oxygen bands are located around 50 to 65 GHz allowing “all weather” monitoring of the Earth’s atmosphere on a worldwide scale;

b) that measurements of temperature at different heights in the atmosphere using spaceborne passive sensors are vital for weather forecasts and climate studies (such as “global change”);

c) that a small number of undetected interference events can have an extremely detrimental effect on numerical weather prediction;

d) that measurements of sufficient accuracy can only be obtained in precise frequency sub-bands from around 50 to 60 GHz dictated by the physical processes of oxygen spectroscopy;

e) that the World Radiocommunication Conference (Geneva, 1997) (WRC-97) Agenda item 1.9.4.3 concerns existing frequency allocations near 60 GHz and, if necessary, their re-allocation to protect Earth exploration-satellite service (EESS) (passive) systems;

f) that around 55 GHz, temperature “sounding” is highly sensitive to interference from terrestrial sources;

g) that the frequency bands 50.2-50.4 GHz and 54.25-58.2 GHz are shared on a co-primary basis between spaceborne passive sensors and the fixed service;

h) that the preferred frequencies and necessary bandwidths for satellite passive sensing are contained in Recommendation ITU-R SA.515;

j) that extensive sharing studies have been carried out as summarized in Annex 1;

k) that restrictions would be required on the operation of fixed links in the band 55.2-55.78 GHz, as detailed in Annex 1;

l) that due to the high vulnerability of passive temperature soundings to interference, the strict compliance of the restrictions in the band 55.2-55.78 GHz on a worldwide basis would be vital for adequate protection of passive sensors;

m) that the enforcement on a worldwide basis of a strict compliance with the required restrictions would not be practicable,

recommends

1 that sharing between spaceborne passive sensors and the fixed service is feasible between 55.78 GHz and 60 GHz;

2 that sharing between spaceborne passive sensors and the fixed service is not practicable between 50 GHz and 55.78 GHz and that spaceborne passive sensors and the fixed service not operate in the same frequency band within this range.

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[*] Throughout this Recommendation, “spaceborne passive sensors” includes sensors on board satellites operating in the Earth exploration-satellite (passive) and space research (passive) services, since the characteristics of these two services are essentially identical throughout the frequency bands under consideration.

ANNEX 1

Sharing between the fixed service and passive remote sensors in the range 50.2-58.2 GHz

1 Introduction

The fixed service and the Earth exploration-satellite (EES) passive and space research (passive) services have co-primary allocations in the bands 50.2-50.4 GHz and 54.25-58.2 GHz. The purpose of this Annex is to review the suitability of these allocations and, where necessary, to develop limitations to be applied to the fixed service to ensure adequate protection of passive remote sensors.

The oxygen absorption in the frequency ranges of interest varies considerably, with a large number of absorption lines, around 60 GHz. The level of absorption used in the sharing studies has been calculated from Recommendation ITU-R P.676. It will be shown that the level of absorption has an important effect on the feasibility of sharing. Figure 1 shows the total absorption on a vertical path from Earth-to-space. The absorption on the ground-space path is reduced as the height of ground above sea level is increased. Fixed link transmitters could operate from locations at a range of altitudes. Throughout this Annex, as a conservative estimate, it is assumed that fixed service transmitters are at 1 000 m above sea level.

At the relatively high frequencies of interest here, indirect propagation effects can be a significant propagation mechanism. As a worst case representative of indirect propagation mechanisms, the studies have considered reflection from building roof tops.

2 Fixed links

In some countries, fixed links have been operated in the bands 50.2-50.4 GHz and 57.2-58.2 GHz. The maximum transmitter power currently achievable is around –17 dBW. The sharing parameters of the fixed service have been derived from details of those systems in current use. To allow for future advances in microwave technology, a transmitter power higher than that currently achievable has been assumed. In the initial sharing analysis, the following parameters in Table 1 of fixed links have been used.

TABLE 1

Fixed service sharing parameters

Transmitter power (dBW)		–10
Minimum bandwidth (MHz)		14
Feeder loss (dB)		0
Antenna gain (dBi) :	– boresight	41
	– 90°off boresight	–10
Antenna elevation angle (degrees)		0
Antenna height above sea level (m)		1 000

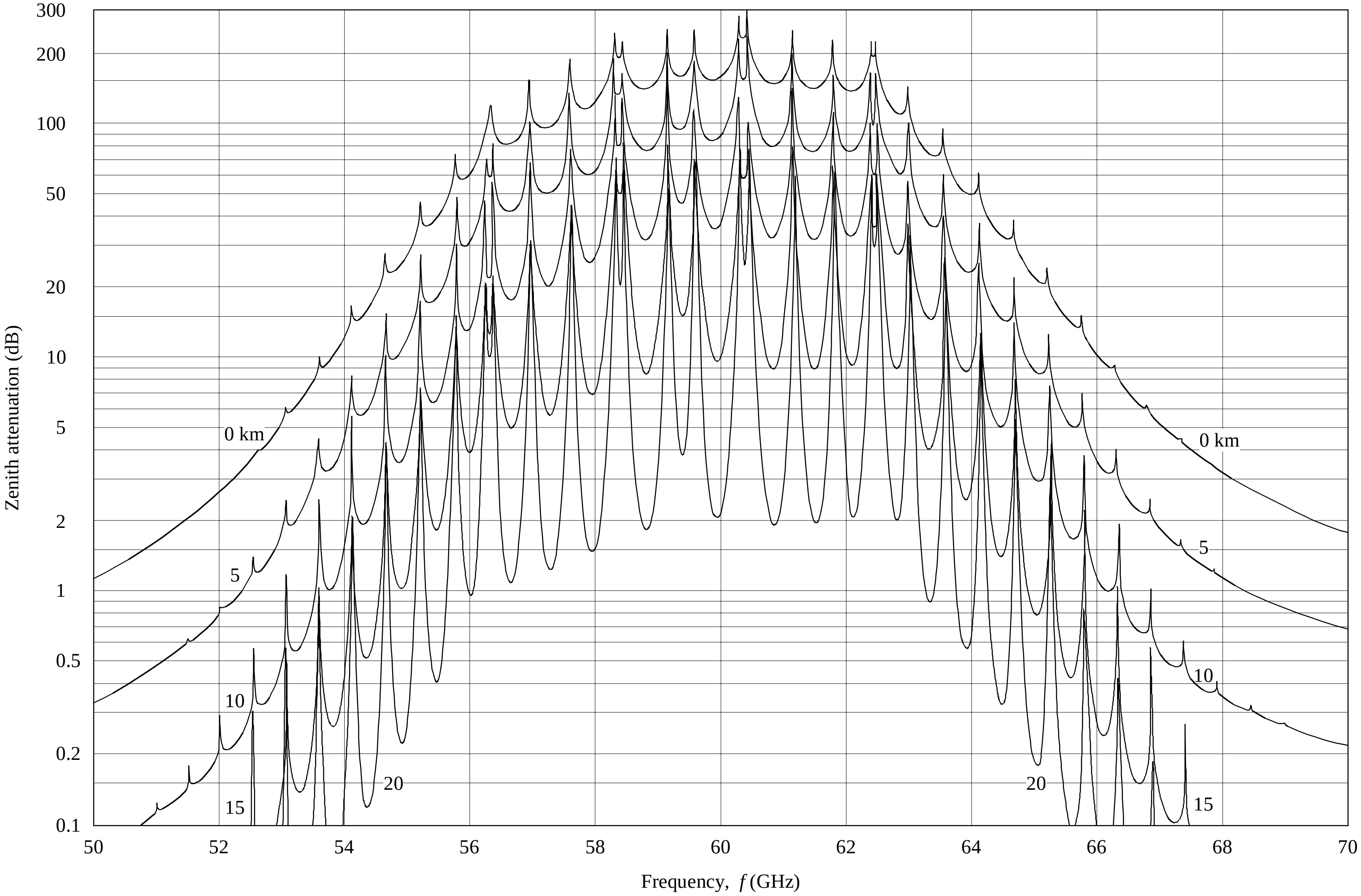
3 Passive sensors

3.1 Current and future systems

Several organizations are currently operating or developing passive sensors which operate in the bands around 55 GHz. These sensors use a mechanically scanning design. The next generation of passive sensor are likely to utilize a pushbroom scanning concept which allows improved radiometric and spatial resolution. The pushbroom type sensor is not expected to be used before 2005.

FIGURE 1

Zenith oxygen absorption for some initial heights



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3.2 Sharing parameters

The pushbroom type of sensor will be more susceptible to interference than the mechanically scanning type used on current sensors. Therefore, a hypothetical pushbroom sensor has been assumed in the studies. The parameters are given in Table 2.

TABLE 2

Passive sensor sharing parameters

Antenna diameter (cm)	45
–3 dB beamwidth (degrees)	1.1
Scanning limits (degrees)	± 50 (cross track)
Antenna gain (dBi)	45
Radiometric resolution (K)	0.1
Swath width (km)	2 300
Pixel size (nadir) (km)	16 diameter
Number of pixels/line	90
Orbit altitude (circular) (km)	850
Orbit inclination (sun-synchronous) (degrees)	98.8

3.3 Interference criterion

Recommendation ITU-R SA.1029 describes the interference criteria for satellite passive remote sensors. For pushbroom sensors operating in the range 50 to 66 GHz, the permissible interference level is –166 dBW in a reference bandwidth of 100 MHz. Because of the significant effect of any interference for the users of the data obtained in these bands, the sharing studies below are on the basis of the limit being exceeded in no measurement cells.

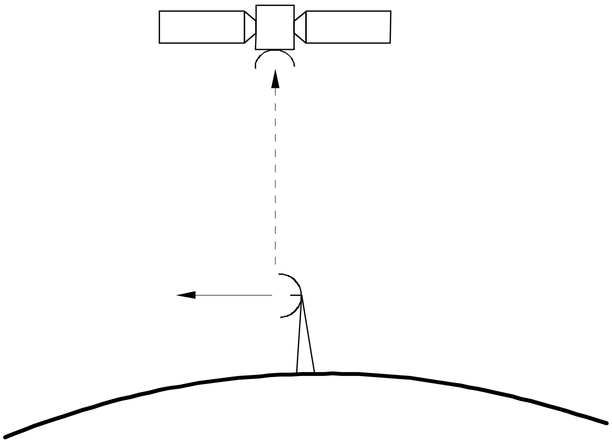
4 Sharing analysis

4.1 Preliminary analysis

If one assumes that fixed links will operate with an antenna elevation angle of around 0°, the worst case direct interference path is the zenith path from fixed link-to-satellite, as shown in Fig. 2.

FIGURE 2

Worst case direct interference path



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The oxygen absorption on the zenith path, from an initial height of 1 000 m, varies from 1.3 dB at 50.2 GHz to more than 100 dB at 58.2 GHz. The bands considered in this paper are divided into a number of slots (as shown in Table 3), defined by the limits of the shared frequency bands and the peaks in the zenith absorption. In each slot, the minimum atmospheric absorption is used to determine the maximum vertically radiated power from the Earth, and hence the maximum number of co-channel interferers.

TABLE 3

Maximum number of co-channel transmitters

Slot No.	1	2	3	4	5	6	7	8
Frequency range (GHz)	50.2-50.4	54.25-54.67	54.67-55.22	55.22-55.78	55.78-56.26	56.26-56.36	56.36-56.96	56.96-57.20
Fixed link maximum transmitter power (dBW)	–10	–10	–10	–10	–10	–10	–10	–10
Fixed link antenna gain (zenith) (dBi)	–10	–10	–10	–10	–10	–10	–10	–10
Fixed link maximum e.i.r.p. to zenith (dBW)	–20	–20	–20	–20	–20	–20	–20	–20
Frequency of absorption minimum (GHz)	50.2	54.25	54.74	55.31	55.89	56.29	56.57	57.19
Satellite altitude (km)	850	850	850	850	850	850	850	850
Free space loss (dB)	185.0	185.7	185.8	185.9	186.0	186.0	186.1	186.2
O_2 absorption from 1 000 m (dB)	1.3	12.8	20.3	32.2	50.5	79.3	71.1	86
Sensor antenna gain (dBi)	45	45	45	45	45	45	45	45
Sensor channel bandwidth (MHz)	15	15	15	15	15	15	15	15
Interference threshold in 100 MHz	–166.0	–166.0	–166.0	–166.0	–166.0	–166.0	–166.0	–166.0
Threshold density (dB(W/15 MHz))	–174.2	–174.2	–174.2	–174.2	–174.2	–174.2	–174.2	–174.2
Maximum e.i.r.p. from ground (dB(W/15 MHz/pixel))	–32.9	–20.7	–13.1	–1.2	17.2	46.1	37.9	52.9
Transmitted vertical e.i.r.p. per fixed link (dB(W/15 MHz))	–19.7	–19.7	–19.7	–19.7	–19.7	–19.7	–19.7	–19.7
Margin (dB)	–13.2	–1.0	6.6	18.5	36.9	65.8	57.6	72.6
Maximum fixed links per sensor channel per pixel	0	0	4	71	4 940	3 801 943	581 186	18 356 222

To determine the feasibility of sharing, one must consider the likelihood of the number of co-channel fixed link transmitters within any 16 km diameter pixel, and within a 15 MHz bandwidth, exceeding the figures given in Table 3.

- In slots 1 and 2, a high level of interference could be caused by a single transmitter. Thus, sharing appears to be unfeasible.
- In slot 3, only a few co-channel transmitters would be required to exceed the interference threshold and thus sharing appears to be unfeasible.
- In slot 4, a reasonable number of fixed links could operate, especially if lower transmitter powers were used.
- In slots 5-8, extremely large numbers of fixed links could operate and thus sharing appears to be feasible.

To more accurately determine the feasibility of sharing in the band 55.22-55.78 GHz, a more detailed sharing study is presented in § 4.2.

4.2 Detailed sharing analysis in the band 55.2-55.78 GHz

This section provides more detailed consideration on the transmitter power of fixed links, the maximum achievable density of links, indirect propagation effects and the effect of the fixed link antenna elevation angle above 0°.

The band can be considered as 55.20-55.78 GHz since the zenith absorption minimum is the same for the band 55.22-55.78 GHz.

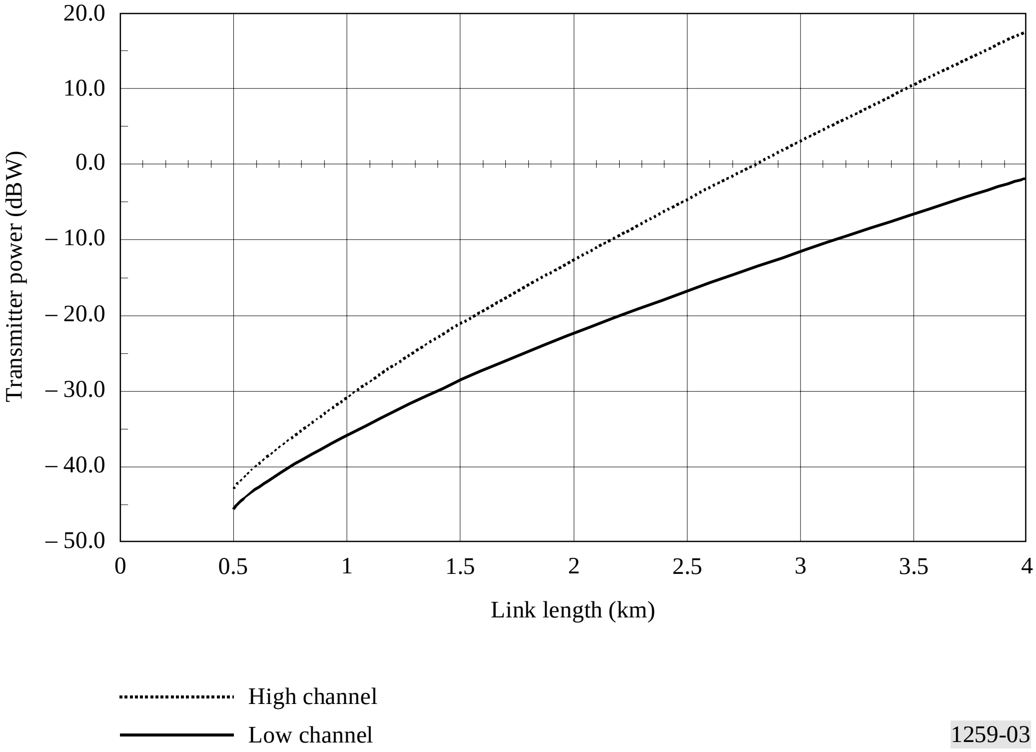
4.2.1 Maximum fixed link power

The existing fixed link channel plan for this band given in Recommendation ITU-R F.1100 covers 54.25-57.2 GHz, so a revised theoretical plan was used. This was based on 55.2-57.2 GHz with a 68.5 MHz lower guard band, a 70 MHz centre gap and a duplex spacing of 966 MHz.

Fixed link bands are arranged in two halves, so that a “go” channel in the lower half is always associated with a “return” channel in the upper half. Link budget calculations based on typical equipment parameters show that a power level of −10 dBW results in an upper limit of ~2 km on link length, due to the high level of attenuation in the upper half of the band. The transmitter power required to cover this distance in the lower half of the band is –23.2 dBW (if 3 dB is allowed for feeder losses at each end), due to the reduced attenuation. Figure 3 shows the required transmitter power for various link lengths.

FIGURE 3

Transmitter power against link length



4.2.2 Maximum fixed link density

A simulation has been performed to determine the theoretical maximum number of fixed links that could be accommodated in a 16 km diameter pixel. The only criteria used were based on interference to and from neighbouring fixed links. This modelled the situation where users might install links without regard to any imposed density limits.

4.2.2.1 Simulation methodology

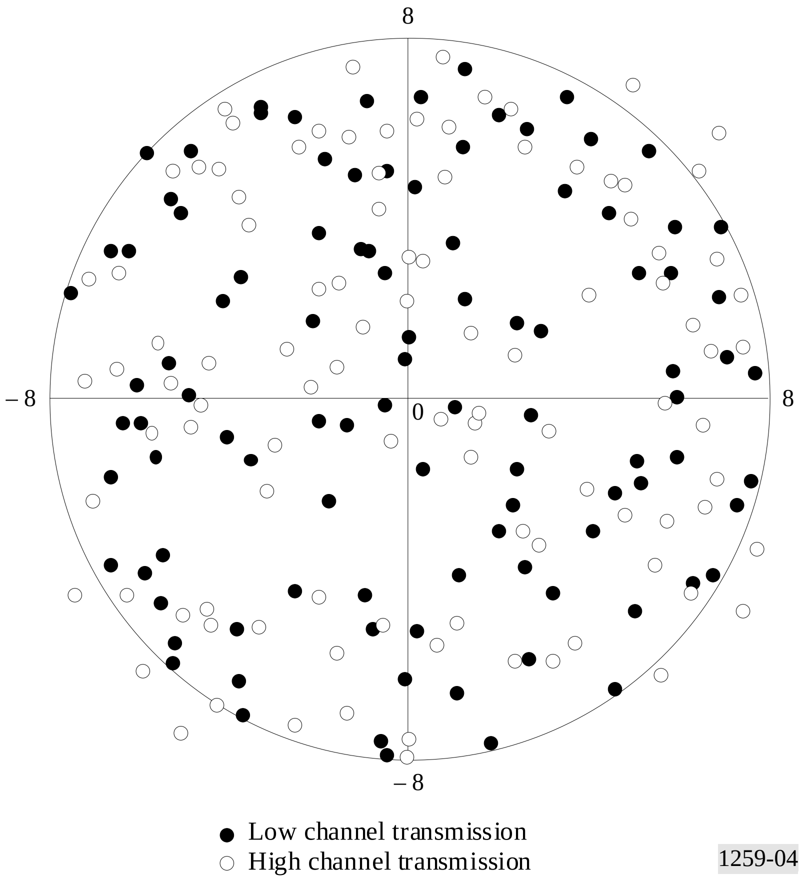
The positions, lengths and directions of the links were chosen at random but bound by a maximum link length of 2 km. The simulation used a free space path loss propagation model. The interference threshold for a single interferer was an *I*/*N* ratio of –10 dB.

The simulation placed links in the test area, each time checking the interference to and from every other link, assigning the new link when the interference levels were below the threshold, and failing the link when the interference levels were above the threshold. This continued until a predetermined number of consecutive assignment failures occurred. At this point it was considered that the practical maximum link density for the test area had been reached as far as link-to-link interference is concerned.

The allowed number of failures was set to 20 and the simulation was run several times. In each case the number of fixed links allocated in the test area was between about 100 and 120 successful assignments. Figure 4 is a graphical representation of how one run of the simulation successfully assigned one hundred links in the test area.

FIGURE 4

100 links randomly allocated in test area



A band in which 20 out of 21 attempted assignments failed would be regarded as full. Thus an estimated figure of around 150 would appear as the maximum theoretical link density for bidirectional links of this type in the test area. This estimation is supported by Fig. 4 which shows that there is hardly any room in the test area for many more in-band transmitters once 100 have already been assigned.

In practice, even this figure would be very difficult to achieve in a real world assignment situation. Links tend to cluster around town centres, hence congestion limits would be reached here while other areas of the pixel were relatively empty. Further reductions in theoretical density would come from:

- co-channel links outside the pixel,
- adjacent channel links,
- nodal deployment of links.

4.2.2.2 Derivation of limits

One can consider 150 to be a conservative estimate of the maximum density of co-channel fixed links. The maximum e.i.r.p. from the ground is –1.2 dB(W/15 MHz/pixel) (from Table 3). Dividing this figure by 150 and scaling to various bandwidths gives the limits in Table 4.

TABLE 4

Maximum vertical e.i.r.p.

maximum e.i.r.p. towards zenith	–23.0 dB(W/15 MHz)
	–13.3 dB(W/140 MHz)
	–23.3 dB(W/14 MHz)
	–34.7 dB(W/MHz)

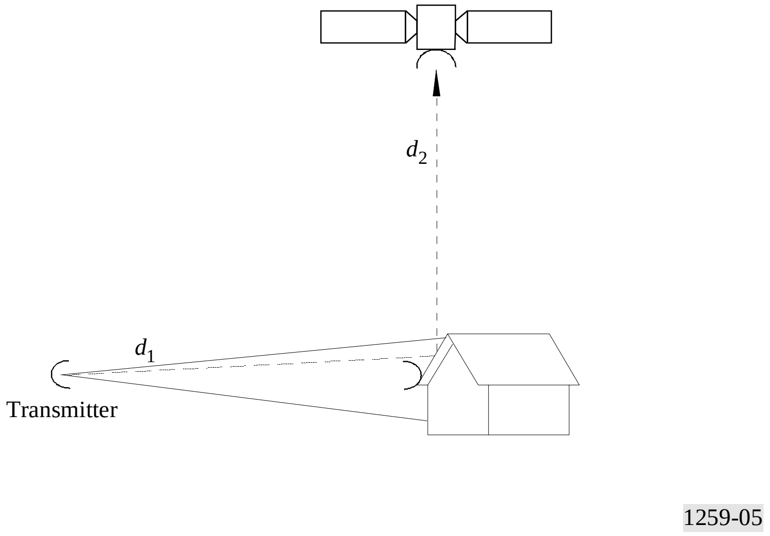
By applying this vertical e.i.r.p. limit to each fixed link transmitter in the band 55.2-55.78 GHz, and bearing in mind the maximum conceivable number of co-channel transmitters is 150, one can be sure that such a limit would ensure that interference by direct propagation would not exceed the sensor threshold, and would allow unhindered operation of fixed links.

4.2.3 Indirect propagation effects

As a representative worst case indirect propagation effect, a rooftop reflection as illustrated in Fig. 5 is considered. The roof is assumed to have an elevation of 45° and the normal of the roof and the incident ray are assumed to be in a vertical plane. For vertical polarisation, the specular reflection from a rooftop may have a reflection coefficient, σ, of up to –10 dB. At the frequencies considered here the size of the Fresnel zone projected onto a roof will typically be a few metres wide so it is feasible to obtain specular reflection from a fixed link beam with a reflection coefficient of –10 dB. It is assumed that full Fresnel reflection occurs and the incident beam is reflected vertically and received by the satellite sensor overhead.

FIGURE 5

Rooftop reflection



The effect of such reflections could be more significant than the direct interference case considered above. Such alignments are however, likely to be exceptional.

At the frequency of 55.22 GHz, the specific attenuation at sea level is 4.5 dB/km. For small values of d_1, the absorption and spreading loss on path d_1 may be ignored.

The maximum e.i.r.p. is then given by:

$$e.i.r.p._{max} = I_{th} - \sigma + 20 \log \left[\frac{4\pi d_2}{\lambda} \right] + \gamma_2 - G_s \tag{1}$$

where:

I_{th} : interference threshold
= –116 dB(W/100 MHz)

γ_2 : minimum gas absorption
= 32,2 dB (1 000 m altitude)

G_s : remote sensor antenna gain
= 45 dBi.

With scaling to various bandwidths, this produces the e.i.r.p. limits given in Table 5.

TABLE 5

Fixed link maximum e.i.r.p.

maximum e.i.r.p.	8.8 dB(W/15 MHz)
	18.5 dB(W/140 MHz)
	8.5 dB(W/14 MHz)
	–2.9 dB(W/MHz)

Bearing in mind the low probability of such alignments, one could be confident that by applying these e.i.r.p. limits to each transmitter of the fixed service, the passive sensor would not suffer unacceptable interference from indirect propagation mechanisms. These limits would allow the maximum link length to reach about 1.5 km.

4.2.4 Effect of fixed link antenna elevation angle

The remote sensors scan ±50° from the nadir in a crosstrack pattern. At the limit of the scan, the beam strikes the Earth’s surface at an elevation angle of 30°. Normally, the increased path loss and absorption on the slant path results in a lower level of interference than the zenith/nadir path. If however, a fixed link antenna was at a high elevation angle, the interference on the slant path could exceed the interference on the zenith/nadir path.

One can determine the elevation angle at which the interference by path b) exceeds the interference by path a) as shown in Fig. 6

A link will be considered at 1 000 m altitude, transmitting with a frequency of 55.22 GHz. For the zenith/nadir path, free space loss, FSL_a, is 185.9 dB and the minimum gas absorption, γ_a, is 32.2 dB. For the slant path, free space loss, FSL_b, is 190.7 dB and the gas absorption, γ_b, is 63.9 dB.

If the fixed link transmitter power is P_T , the fixed link antenna gain at an angle φ is $G(\varphi)$, and the satellite sensor antenna gain is G_S, then the interference caused on each alignment is:

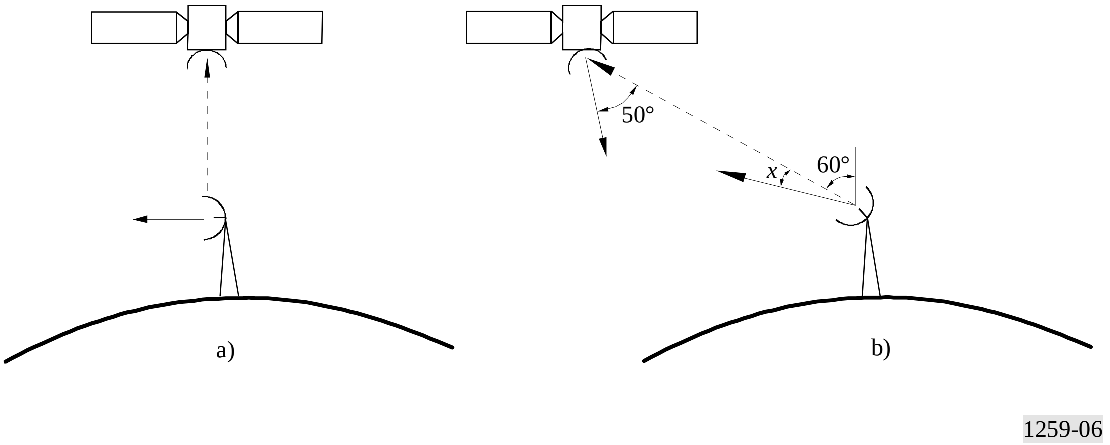
$$I_b = P_T + G(x) - FSL_b - \gamma_b + G_S \tag{2}$$

and

$$I_a = P_T + G(90) - FSL_a - \gamma_a + G_S \tag{3}$$

FIGURE 6

Zenith/nadir path a) and slant path b)



Equating I_a to I_b leads to:

$$G(x) = G(90) - FSL_a + FSL_b - \gamma_a + \gamma_b \tag{4}$$

For a typical high performance antenna operating in this band we can assume $G(90) = -10$ dBi. Thus,

$$G(x) = 26.5 \text{ dBi}$$

An antenna gain of 26.5 dBi could be expected for angles only within 5° of boresight. Thus if the angle between the fixed link terminal antenna boresight and the ray to the satellite antenna exceeds 5°, one can be sure that the interference on path a) exceeds the interference on path b).

Since the beam of the satellite sensor strikes the Earth with a minimum elevation of 30°, a limit on the antenna elevation angle of 25° will ensure that direct interference cannot exceed the level assumed in the direct interference analysis in § 4.2.1.

5 Conclusions

The conclusions can be broken down band by band:

50.2-50.4 GHz	Sharing is not feasible
54.25-55.2 GHz	Sharing is not feasible
55.2-55.78 GHz	Sharing is feasible with the following restrictions: maximum e.i.r.p.: – 2.9 dB(W/MHz) maximum e.i.r.p. towards zenith: –34.7 dB(W/MHz)(1) Maximum elevation angle: 25°
55.78-58.2 GHz	Sharing is feasible with no restrictions on the fixed service.

(1) Assuming that no more than 150 co-channel links per pixel (16 km diameter) can operate due to intraservice interference.

The restrictions in the band 55.2-55.78 GHz would allow the fixed service to operate with a maximum link length of around 1.5 km.

Because of the vulnerability of passive sensing to interference, the above restrictions in the band 55.2-55.78 GHz must be carefully observed all over the Earth's surface. The practicability of ensuring strict compliance with these restrictions on a worldwide basis gives rise to serious concerns.